Investigating the ecology and behavior of blue whales (*Balaenoptera musculus*) in the Gulf of Corcovado, Chile
Technical Report 2016

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Technical Report

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Front Cover Figure Caption:
DTAG deployment on a blue whale. Photograph taken by Gloria Howes under Chilean research permit: Ministerio de Economia, Fomento y Turismo, Subsecreteria de Pesca y Acuicultura, MERI 488-FEB-2016 Ballena Azul, Golfo Corcovado.

Introduction

Blue whales are known principally by two contrasting accolades, firstly, as being the largest animal to have ever lived on Earth, and secondly, as having been hunted to near extinction during twentieth century whaling. During the whaling era over four thousand animals were caught in Chilean waters alone (Williams et al. 2011). The species has been slow to recover from almost total decimation and hence a valuable discovery was made in 1993, when a small blue whale population of 232 individuals was found in the Gulf of Corcovado (GoC) in the Chiloense Ecoregion of Southern Chile (Hucke-Gaete et al. 2004). Genetic, acoustic and morphometric studies indicate that these blue whales are part of a wider Southeast Pacific population that is distinct from both the Antarctic (*B. musculus intermedia*) and "pygmy" (*B. musculus brevicauda*) blue whale subspecies (Branch et al. 2007, Buchan et al. 2014, Torres-Florez et al. 2014). Further investigations are required to establish the degree of isolation of the population and the health and viability of the individuals within it. Such knowledge is vitally important and will aid Chilean policy makers in generating informed management decisions regarding the conservation of this population.

In 2014 some encountered animals were observed in poor body condition, appearing emaciated. This led to a collaboration with Dr. Michael Moore WHOI) and Dr. John Durban (NOAA) in 2015 to measure and assess blue whale body condition using photogrammetry and an unmanned hexacopter (Durban et al. 2016). To further address this issue, collaborations with Dr. Joseph Warren (Stony Brook University) and Dr. Paolo Segre (Stanford University) were sought to investigate both prey availability and the energetics of blue whale foraging in the GoC.

Long-Term Goals

The principle goal of this project was to continue the investigation into the ecology, foraging and acoustic behavior of blue whales in the GoC, Chile, that began in 2014 with the support of the Melimoyu Ecosystem Research Institute (MERI).

Objectives

This investigation had four principle objectives, (1) to obtain data on the diving, foraging and vocal rates of individual blue whales in and around the GoC (Fig. 1), through the deployment of suction cup attached digital acoustic tags (DTAGs), (2) to collect biopsy samples from encountered blue whales, (3) to conduct prey mapping and prey sampling trawls in the vicinity of foraging whales and (4) deploy a suction cup attached video and movement recording (CATS) tag to study body kinematics and foraging strategies.

DTAG Study

As in the previous two field seasons, this investigation set out to acquire data on the ecology, foraging and acoustic behavior of individual blue whales in and around the GoC, Chile (Fig. 1). This was undertaken via the deployment of suction cup attached digital acoustic tags (DTAGs; Fig. 2). DTAGs are miniature sound and orientation recording tags developed at WHOI (Johnson and Tyack 2003). These tags contain a VHF transmitter used to track the tagged whale during deployment and to retrieve the tag after release. DTAGs record sound at the whale, as well as depth, and 3-dimensional acceleration and magnetometer information, and thus provide data on vocal, movement and dive behavior. The tag is attached with four suction cups using a hand-held 8 m carbon fiber pole (Fig. 2), and can be programmed to release after durations of up to 30 hours.

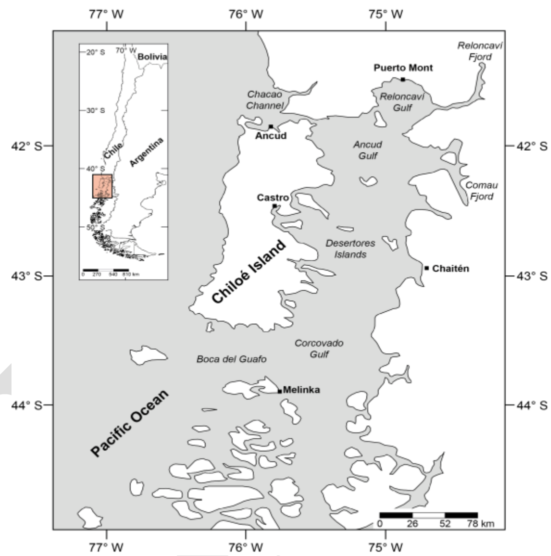

Figure 1. Maps indicating the location of the study region on the coast of Chile (inset) and the principle study area, the Gulf of Corcovado.

Biopsy Sampling

To increase our understanding of the genetic stock from which the blue whales of the GoC originate and to investigate the health and contaminant levels of these whales, remote biopsy sampling was conducted opportunistically. Samples collected are contributing to a global stock assessment of blue whales being conducted by NOAA SWFSC, La Jolla, USA. Equally, these samples are contributing to a broad ecosystem health study of the GoC being led by Gustavo Chiang and Paulina Bahamonde.

Prey Mapping and Sampling

To further investigate foraging and habitat use, prey mapping surveys and qualitative zooplankton samples were taken at the locations of feeding whales. Prey sampling net trawls were used to collect prey in order to characterize food sources. This data will contribute to the food web modeling, stable isotope analysis and contaminant biomagnification investigations being undertaken by Fundación MERI in the region.

Kinematics Study

To compliment the DTAG study, a video and movement recording tag built by Customized Animal Tracking Solutions (CATS) were deployed (Fig. 6). These CATS tags enable scientists to investigate the mechanics of motion and the forces required to generate motion. This study will employ them to investigate the kinematics of blue whales foraging in the GoC, facilitating studies of body condition and the energetic requirements of these animals.

The months of February and March were chosen to conduct the field effort, based on historical blue whale sightings, acoustic detections and weather data.

Project Personnel and Research Vessel

Cruise personnel included Gustavo Chiang (MERI) who acted as the chief scientist, Alessandro Bocconcelli (WHOI) who was in charge of field operations, Leigh Hickmott (Open Ocean Consulting and the University of St. Andrews) was responsible for tag deployments, biopsy sampling and data collection, Paulina Bahamonde (MERI) acted as the geneticist, being responsible for processing genetic samples, Joseph Warren (Stony Brook University) led the

Figure 2. The DTAG (bottom left) and the attachment method via hand-held pole (top left); images on the right show the tag attached to a blue whale with its four suction cups and the tag's small size relative to the animal's size.

prey mapping and sampling research, Paolo Segre (Stanford University) headed the kinematic study and tag analysis, Gloria Howes (MERI) collected photo-identification images and assisted with field logistics. Laela Sayigh (WHOI) acted as the whale vocalization lead analyst.

The RV *Khronos* was employed as the principle survey vessel (Fig. 3).

Field Methods

Each day, weather and sea-state permitting, visual search efforts to detect marine mammals began at sunrise on the main vessel. All cetacean sightings were recorded in LOGGER (see Tracking and Visual Data Collection below and Appendix I), and where possible photo-identification images were collected. Once blue whales were detected, the possibility for tagging and or photogrammetry was assessed and if conditions were suitable tagging or photogrammetry commenced.

Figure 3. The RV *Khronos*.

Tracking, visual data collection and photo-identification

To visually search for study animals, and to observe the behavior of the animals during tagging and tracking, a marine mammal observer platform was installed on the deck of the flying bridge of the *Centinela*. Observers scanned with the naked eye and 7 X 50 binoculars. This platform was equipped with a computer running the behavior logging program LOGGER (recording data such as species, group size, behavior, latitude/longitude; see Appendix I) and a VHF digital direction finder system for tracking the tag. Video and/or digital photographs to record species and any identifying marks were collected whenever possible.

Tagging
The tagging boat was deployed with a driver (Bocconcelli), photographer (Howes) and tagger (Hickmott) to deliver the DTAG or CATS tags using the hand-pole. Attempts were made to tag each whale in a group when whales appeared to be coordinated and were likely to remain together, thus minimizing the risk of tag loss.

Visual observers on the main vessel helped direct the tag boat towards animals, monitored tagging approaches, and ensured tagging permit compliance. Data sheets and computer data logs were kept on the main vessel and tag boat, detailing each tagging approach. If tagging was unsuccessful after several approaches, tagging efforts were suspended. During tagging efforts video and/or 35mm digital photographs were collected whenever possible, as were sloughed skin samples (see Genetic samples below).

Once a whale was successfully tagged and all relevant data collected by the tag team, the zodiac returned to the main vessel. The main vessel was then used to track and maintain visual and photo-identification efforts for the duration of tracking and behavioral observations (except for night hours). At night, the main VHF receiving antenna on the vessel was used for radio tracking of the tagged whale or whales (the main vessel was capable of tracking more than one animal using separate sets of antennae). Tagging attempts continued during daylight hours and a day was only considered complete when all tags were recovered and there was no longer enough daylight to attempt further tagging. Tags were recovered with a dip net from the main vessel. Tag data were offloaded onboard, and the tags were recharged and sterilized for subsequent use.

Genetic Samples
Biopsy Sampling - To collect skin and blubber samples from free ranging blue whales, a 150lb draw weight Barnett Wildcat crossbow was used to deploy biopsy bolts fitted with a sterile stainless steel cutting tip (50 or 25mm X 5mm)(Fig. 4). Collected biopsy samples were stored RNAlater, a stabilization and storage liquid for later analysis.
Sloughed Skin - Sloughed skin samples were opportunistically collected from the DTAG's suction cups, catalogued and stored in RNAlater.

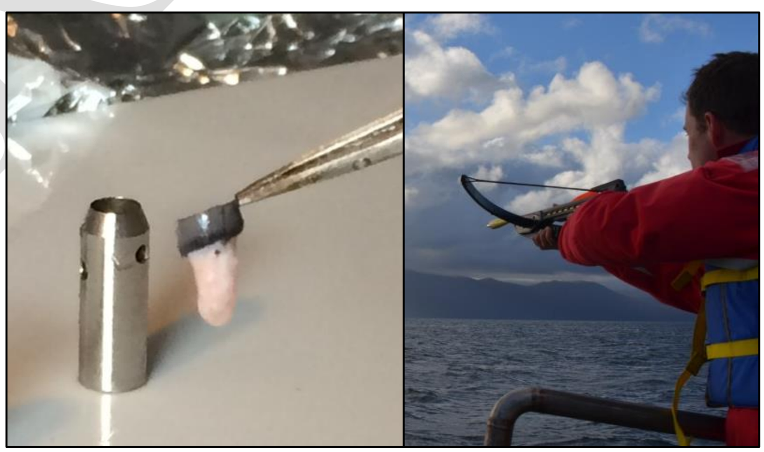
Figure 4. Stainless steel biopsy tips were used to collect skin and blubber samples. Biopsy bolts were deployed using a crossbow.

Prey Mapping

A two-frequency (38 and 200 kHz) scientific echosounder was used to map the distribution and abundance of fish and zooplankton during the study. The system was mounted on the port side of the RV Khronos at a depth of 1m (Fig. 5) and collected data from ~ 2m depth to the bottom of the water column with a vertical resolution of approximately 10 cm.

Figure 5. The scientific echosounder system was pole mounted on the port side of the RV Khronos for underway data collection (left) and could be raised for rapid transit (middle, the orange object is the transducer). The data collection and storage system were located on the bridge of the vessel (right, the pig is a lab mascot).

Prey Sampling

A 250 µm mesh, 50 cm diameter and 3 m long zooplankton net was towed horizontally from the RV Khronos at 2 knots for 20-30 minutes. Once the trawl was complete the net was hauled to the surface, where the accumulated plankton was separated by size and species, labelled and stored at -20 °C in preparation for analysis.

All genetic and prey sampling specimens will contribute to analysis being conducted by Dr. Gustavo Chiang (University of Concepcion, Chile) as part of a wider study: 'Biomagnification and potential effects of Persistent Organic Pollutants (POPs) and trace metals in the aquatic food webs of the Antarctic Peninsula and Patagonia'.

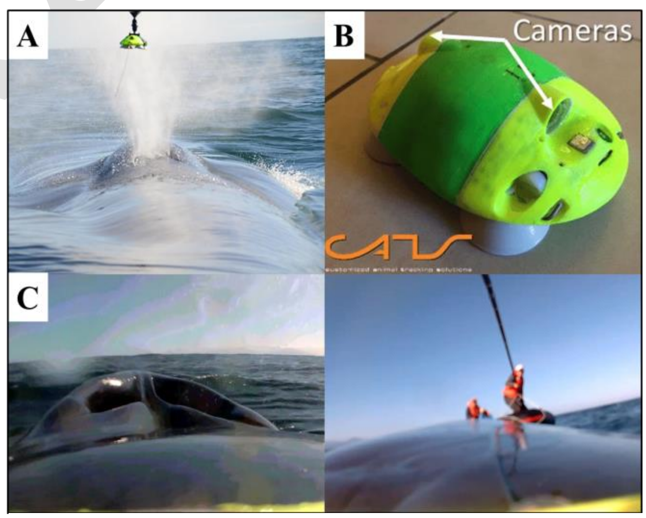

Figure 6. The CATS tag. (A) Tag about to be deployed, (B) the tag with forward and rear facing cameras, (C) front and rear images from the tag as it is deployed.

CATS Tagging

The CATS tag is capable of recording video, fine-scale three dimensional movement data, pressure and GPS location data (Fig. 6). The tag attaches with suction cups and is deployed using a hand pole. The video and movement data recorded by the tag provide unique data to assess the kinematics and foraging stratagies of feeding blue whales.

Results

Field Effort

A 16 day cruise was completed (17th February to 3rd March 2016), departing from the port of Dalcahue, Chiloé Island, Chile. Search effort was planned to focus within the GoC and visit both historic blue whale habitat use areas (Melinka, Melimoyu and Tic Toc) and productive areas found during the 2015 cruise (Chaitén, Islote Nihuel and Chumilden). As in 2015, it became apparent during the cruise that the north eastern region of the GoC was more productive and resulted in the greatest number of blue whale sightings. During the 16 day trial, 674 nm were covered during 157 hours of 'on effort' surveying (Fig. 7).

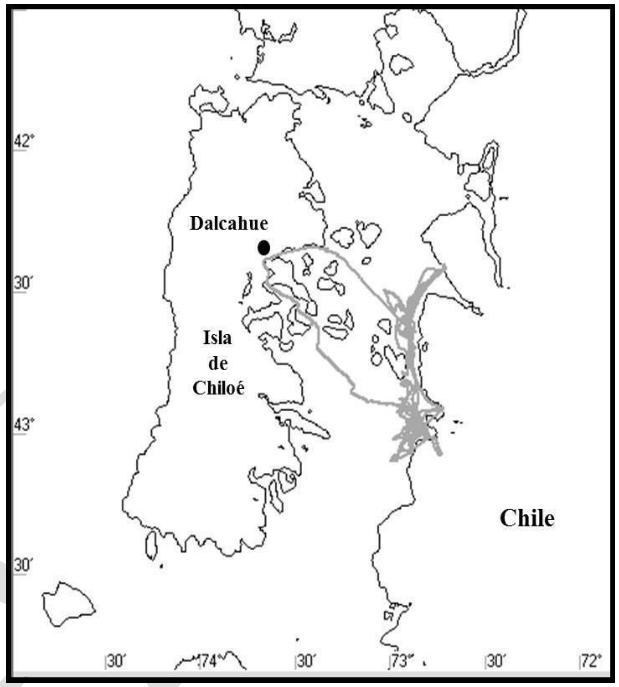

Figure 7. The study area and grey vessel track of the RV Khronos, indicating where the research effort was conducted.

The survey effort resulted in 213 sightings of six mammal species, with sightings being made on each of the 16 survey days (Table 1). Four different cetacean species were recorded, with blue whales comprising 92 % of the 168 cetacean sightings (Table 1).

In addition to the cetacean detections, 45 sightings of two otariid species, the South American fur seal (*Arctocephalus australis*) and the South American sea lion (*Otaria flavescens*) were made (Table 1).

Photo-identification

5,162 photo-identification images were taken of two cetacean species during 76 encounters (Table 2). 75 blue whale groups containing between one and five individuals were photo documented between the 18th February and 03th March (Tables 2, 3a, 3b and Appendix I). 43 individual blue whales were photo-identified, 38 of which were new whales (Tables 3a and 3b). Five blue whales were resights from previous years, four were first identified in 2015 and one animal, Bm005 was first observed in 2014 (Appendix I). 13 of the 2016 photo-identified whales were observed on more than one of the 2016 survey days, 10 on two different days and three whales on three different days.

Scientific Name	Common Name (Spanish)	Common Name (English)	Number of Sightings	Mean Group Size, SD (Range)
Arctocephalus australis	Lobo fino	South American fur seal	23	1.3, 0.6 (1 – 3)
Balaenoptera musculus	Ballena azul	Blue whale	155	1.2, 0.4 (1 – 3)
Cephalorhynchus eutropia	Delfín chileno	Chilean dolphin	2	3.5, 2.1 (1 – 5)
Lagenorhynchus australis	Delfín austral	Peale´s dolphin	10	2.7, 1.3 (1 – 5)
Megaptera novaeanglinae	Ballena Jorobada	Humpback whale	1	1, 0 (1)
Otaria flavescens	Lobo marino	South American sea lion	22	1.4, 0.8 (1 – 4)

Table 1. Table of mammal species recorded, with the number of sightings per species, mean group size, standard deviation and ranges.

Scientific Name	Common Name	Number of Photo-ID Encounters
Balaenoptera musculus	Blue whale	75
Lagenorhynchus australis	Peale´s Dolphin	1

Table 2. Marine mammal species documented using photo-identification, with the number of encounters per species.

DTAG Study

During the cruise eight different adult blue whales were tagged using the DTAG. Six of these deployments resulted in the collection of 38 hours 14 minutes of tag data (Table 4). One tag malfunctioned and did not record data and one tag was lost and could not be recovered. From the six successful deployments, deployment durations had a mean of 6 hours 43 minutes, with the longest deployment being 12 hours 45 minutes. As in previous years, sloughed skin samples were recovered from the tag suction cups and genetic samples were collected from four of the deployments (Table 5).

The maximum dive depth recorded by the DTAG was 126 meters and tag data indicates that animals were regularly diving to between 60 and 120 meters to forage (Fig. 8). The shallow nature of the dives indicates that prey are present in the upper part of the water column. We are currently exploring the data to quantify a diurnal shift from deep ~100 m foraging dives during daylight hours, to shallow near surface feeding at night in response to a diurnal vertical migration of their primary krill prey. The dive data being accumulated during this study is providing an insight into the high degree of time that blue whales in the region spend near the surface, highlighting the risk this species may be exposed to in the Gulf from the threat of ship strikes, particularly at night (Fig. 9).

Date	**EncSeq**	**Latitude**	**Longitude**	**Time (local)**	**Group Size**	**ID's**	**Age Class**
18-Feb-2016	1	-42.88320	-73.12686	11:31	1	Bm032	Adult
18-Feb-2016	2	-42.89784	-72.98223	13:14	1	Bm033	Adult
18-Feb-2016	3	-42.89993	-72.97146	13:21	1	Bm034	Adult
18-Feb-2016	6	-42.90653	-72.94589	14:37	1	Bm035	Adult
18-Feb-2016	7	-42.91575	-72.88223	16:44	2	Bm032	Adult
						Bm036 (T)(B)	Adult
19-Feb-2016	1	-42.95552	-72.88731	11:25	1	Bm037 (T)	Adult
19-Feb-2016	2	-42.95863	-72.89201	11:27	1	Bm038	Adult
19-Feb-2016	8	-42.91293	-72.93462	20:06	2	Bm039	Adult
						Bm040	Adult
21-Feb-2016	2	-42.93982	-72.86562	16:49	2	Bm041 (B)	Adult
						Bm042	Adult
22-Feb-2016	1	-42.94008	-72.85789	8:32	1	Bm043	Adult
22-Feb-2016	2	-42.88766	-72.88170	11:06	2	Bm019	Adult
						Bm044	Adult
22-Feb-2016	3	-42.86476	-72.87661	11:38	1	Bm045 (C)(B)	Adult
23-Feb-2016	1	-42.6473	-72.89688	9:13	3	Bm036	Adult
						Bm045	Adult
						Bm046	Adult
23-Feb-2016	2	-42.65437	-72.91922	11:40	1	Bm029	Adult
23-Feb-2016	3	-42.58422	-72.90466	13:13	4	Bm005	Adult
						Bm029	Adult
						Bm047 (T)	Adult
						Bm048	Adult
23-Feb-2016	4	-42.58759	-72.90874	15:31	3	Bm048	Adult
						Bm049	Adult
						Bm050	Adult
24-Feb-2016	1	-42.61956	-72.90085	10:20	1	Bm029	Adult
24-Feb-2016	2	-42.61846	-72.89774	10:54	1	Bm050 (C)	Adult
24-Feb-2016	3	-42.60461	-72.90247	15:59	2	Bm050	Adult
						Bm051	Adult
25-Feb-2016	1	-42.56159	-72.92437	9:44	1	Bm010	Adult
25-Feb-2016	2	-42.56246	-72.92937	9:49	1	Bm026	Adult
25-Feb-2016	7	-42.54527	-72.95419	10:23	1	Bm052	Adult
25-Feb-2016	9	-42.56575	-72.97550	10:46	1	Bm048	Adult
25-Feb-2016	11	-42.58178	-72.90659	12:51	1	Bm053	Adult
26-Feb-2016	1	-42.99051	-72.87564	15:58	1	Bm054 (T)	Adult
28-Feb-2016	1	-43.05439	-72.93648	13:33	1	Bm055	Adult
28-Feb-2016	2	-43.05580	-72.94138	13:42	1	Bm060 (C)(T)	Adult
28-Feb-2016	3	-43.05803	-72.94950	14:01	1	Bm047	Adult
28-Feb-2016	4	-43.06036	-72.95380	14:05	1	Bm057	Adult
28-Feb-2016	6	-43.05590	-72.94810	14:35	1	Bm058	Adult
28-Feb-2016	7	-43.01289	-72.89484	15:22	1	Bm046	Adult
28-Feb-2016	13	-43.00582	-72.91969	17:05	2	Bm046	Adult
						Bm053	Adult

Table 3a. Blue whale encounter and photo-identification summaries from all encounters in February. (T) = tagged with a DTAG, (C) = tagged with a CAT tag and (B) = animal was biopsied.

Date	EncSeq	Latitude	Longitude	Time (local)	Group Size	ID's	Age Class
29-Feb-2016	1	-43.07435	-72.96503	9:01	4	Bm019	Adult
						Bm026	Adult
						Bm046	Adult
						Bm059	Adult
29-Feb-2016	2	-43.09190	-72.98623	10:31	2	Bm026	Adult
						Bm060 (C)	Adult
1-Mar-2016	1	-42.90102	-72.86783	14:30	2	Bm061	Adult
						Bm062	Adult
1-Mar-2016	2	-42.68047	-72.87934	16:46	1	Bm063	Adult
1-Mar-2016	3	-42.64631	-72.91191	17:21	1	Bm029	Adult
1-Mar-2016	5	-42.65032	-72.93481	18:02	2	Bm052	Adult
						Bm064	Adult
2-Mar-2016	1	-42.58027	-72.90230	8:37	2	Bm065 (T)	Adult
						Bm066	Adult
2-Mar-2016	2	-42.60742	-72.92172	9:43	5	Bm052 (T)	Adult
						Bm065	Adult
						Bm066	Adult
						Bm067	Adult
						Bm068	Adult
3-Mar-16	1	-42.60397	-72.92106	10:39	2	Bm065 (B)	Adult
						Bm069 (B)	Adult
3-Mar-16	4	-42.36602	-73.26974	16:30	1	Bm070	Adult
3-Mar-16	5	-42.34818	-73.32527	17:13	1	Bm034	Adult

Table 3b. Blue whale encounter and photo-identification summaries from all encounters in February and March. (T) = tagged with a DTAG, (C) = tagged with a CAT tag and (B) = animal was biopsied.

Date	Animal ID	Age Class	Deployment ID	Deployment Duration (Hr:min)	Deployment Time (local)	Deployment Location
18-Feb-2016	Bm036	Adult	bm16_049a	12 hrs 45 min	17:47	-42.90805 -72.89255
19-Feb-2016	Bm037	Adult	bm16_050a	6 hrs 49 min	14:37	-42.94561 -72.8404
23-Feb-2016	Bm047	Adult	bm16_054a	8 hrs 46 min	13:58	-42.57874 -72.90897
26-Feb-2016	Bm054	Adult	bm16_057a	0 hrs 15 min	16:00	-42.98696 -72.87453
26-Feb-2016	Bm054	Adult	bm16_057b	Tag lost - no data	16:50	-42.9742 -72.87505
28-Feb-2016	Bm060	Adult	bm16_059a	0 hrs 39 min	17:01	-43.00564 -72.91887
2-Mar-2016	Bm065	Adult	bm16_062a	Tag malfunctioned no data	10:09	-42.60157 -72.91282
2-Mar-2016	Bm052	Adult	bm16_062b	9 hrs 00 min	10:50	-42.61817 -72.91801

Table 4. Blue whale DTAG deployment summaries.

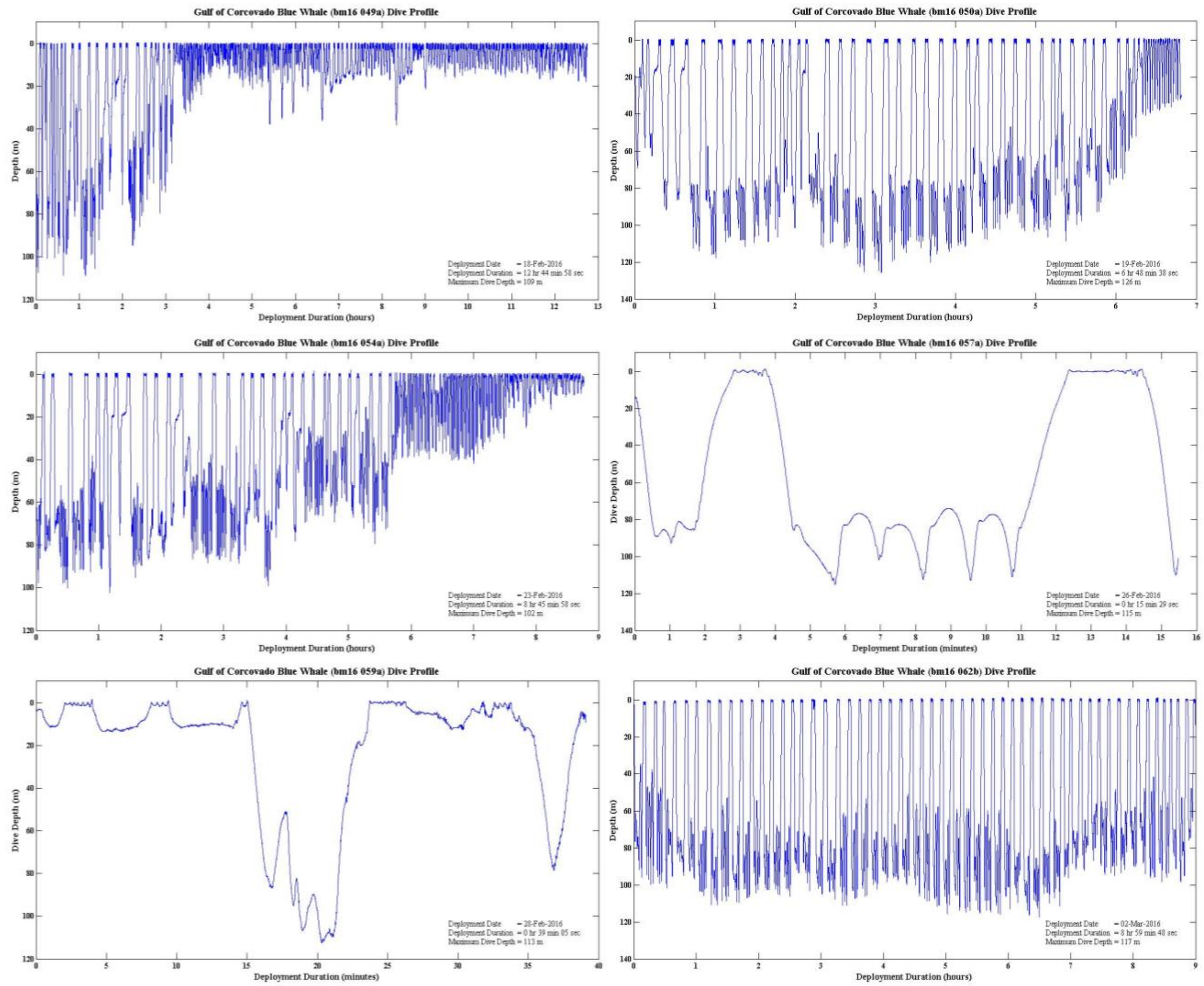

Figure 8. Dive profiles of six tagged blue whales. Deployment duration in hours (x axis) and dive depth in meters (y axis).

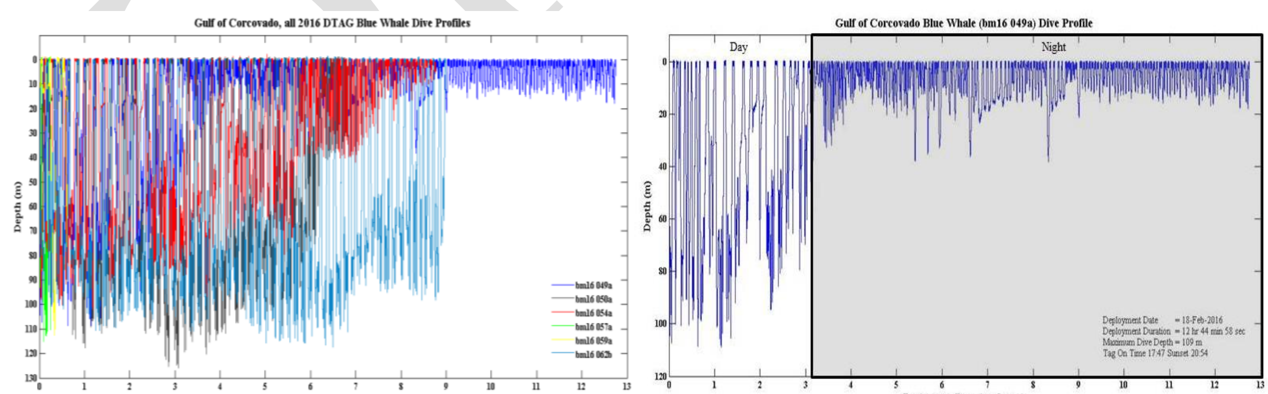

Figure 9. Dive profiles of the six tagged blue whales. Deployment duration in hours (x axis) and dive depth in meters (y axis).

DTAG Acoustic Data Analysis

DTAG data are currently being analyzed at WHOI, led by Mark Saddler and Laela Sayigh.

Below is a summary of the current analysis.

Summary Statement:

We present a characterization of the Chilean blue whale vocal repertoire and develop a modified method of using DTAG accelerometers to identify calling blue whales.

Abstract

Vocal behavior of blue whales (Balaenoptera musculus) in the Gulf of Corcovado, Chile was analyzed using both audio and accelerometer data from digital acoustic recording tags (DTAGs). Over the course of three austral summers (2014, 2015, 2016), seventeen tags were deployed, yielding 124 hours of data. We report the occurrence of Southeast Pacific type 2 (SEP2) calls (Fig. 10), which exhibit peak frequencies, durations, and timing consistent with previous recordings made using towed and moored hydrophones. We also describe tonal downswept (D) calls, which have not been previously described for this population. Since being able to accurately assign vocalizations to individual whales is fundamental for studying communication and for estimating population densities from call rates, we further examine the feasibility of using high-resolution DTAG accelerometers to identify low-frequency calls produced by tagged blue whales. We describe a method of cross-correlating acoustic signals with simultaneous tri-axial accelerometer readings in order to analyze the phase as well as the amplitude of body vibrations associated with low-frequency calls. Analyzing the phase match of acceleration and audio signals as well as the amplitude of body vibrations provides a reliable method of determining if an acoustic signal is associated with a detectable body vibration. Our results suggest that vocalizations from nearby individuals are capable of exciting detectable body vibrations in the tagged whale. We propose a solution to identifying which of the accelerometer-detected calls originate from the tagged animal by using cross-correlation of acceleration vectors

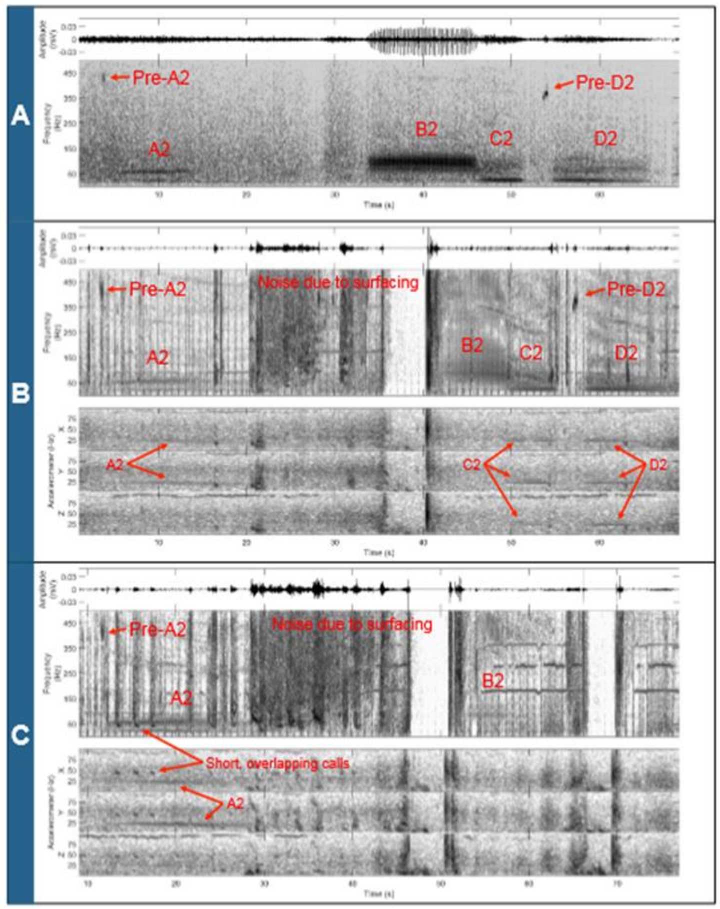

Figure 10. Audio and accelerometer spectrograms of SEP2 calls.

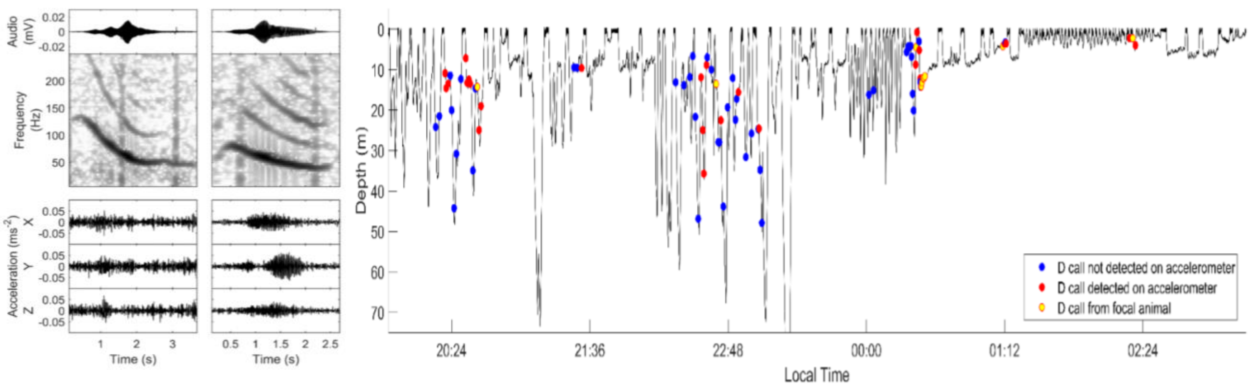

Figure 11. D calls recorded on the tag hydrophone and tri-axial accelerometer (left plot). The occurrence of D calls on a dive profile (right plot).

between calls in order to find signature vibration patterns associated with sounds produced within the tagged whale.

This research has been submitted for peer review and awaits publication.

Genetic Samples

A total of 11 genetic samples were collected from blue whales, five biopsies and six sloughed skin samples collected from tagged animals (Table 5). These 11 samples represent genetic samples from 8 different individuals. All 2016 genetic samples are currently being stored in a -80° freezer at the Andrés Bello National University, Santiago, Chile. Paulina Bahamonde is currently working to establish effective techniques to process the samples as part of a MERI biomagnification and Persistent Organic Pollutants (POPs) investigation.

Genetic samples collected in 2015 have been sent to the USA and are still in the process of being analyzed in a collaborative partnership between NOAA and MERI.

Date Collected	Sample Number/ID	Species	Animal ID	Collection Method	Latitude (SOUTH)	Longitude (WEST)
18-Feb-2016	BM201602_01	*B. musculus*	Bm036	Biopsy	-42.90628	-72.89344
19-Feb-2016	BM201602_49A	*B. musculus*	Bm036	DTAG skin sample	-42.97504	-72.91603
21-Feb-2016	BM201602_02	*B. musculus*	Bm041	Biopsy	-42.95463	-72.86699
22-Feb-2016	BM201602_03	*B. musculus*	Bm045	Biopsy	-42.72376	-72.8758
23-Feb-2016	BM201602_053A	*B. musculus*	Bm045	CAT-TAG skin sample	-42.56905	-72.88567
25-Feb-2016	BM201602_055B	*B. musculus*	Bm050	CAT-TAG skin sample	-42.72405	-72.89481
26-Feb-2016	BM201602_057a	*B. musculus*	Bm054	DTAG skin sample	-42.98041	-72.87879
28-Feb-2016	BM201602_132	*B. musculus*	Bm060	DTAG skin sample	-42.97625	-72.90768
2-Mar-16	BM201603_62A	*B. musculus*	Bm065	DTAG skin sample	-42.77834	-72.88235
3-Mar-16	BM201603_04	*B. musculus*	Bm069	Biopsy	-42.60143	-72.90578
3-Mar-16	BM201603_05	*B. musculus*	Bm065	Biopsy	-42.59847	-72.89997

Table 5. Summary information of the collected genetic samples.

Prey Mapping

The horizontal resolution of the system was dependent on ship speed (typically 5 kts or less) but averaged approximately 2 m between pings. Data were collected on 11 days of the cruise with bad weather preventing data collection on Feb 20, Feb 25, and March 01. A total of 367.6 km of acoustic survey were conducted with the majority of these data occurring during focal follows of tagged blue whales. Acoustic survey data were collected over a broad area of the GoC (Fig. 12) covering both deep and shallow water habitats.

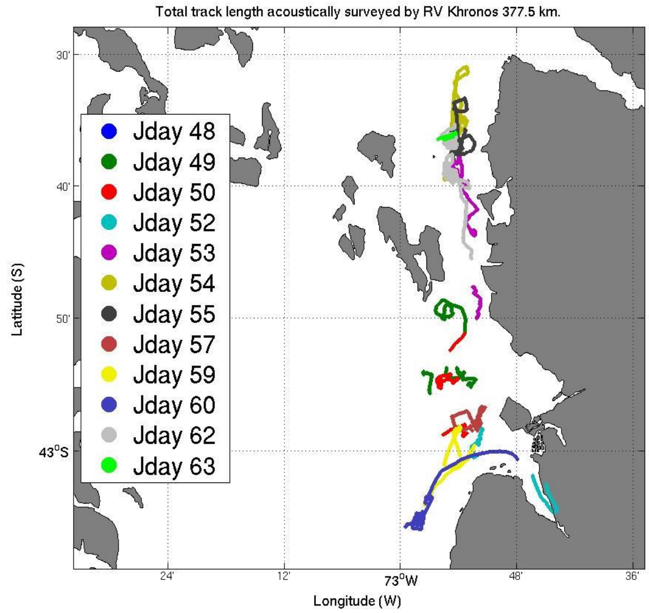

Figure 12. Cruise tracks showing where acoustic prey mapping survey data were collected.

Preliminary examination of the data found that both fish and zooplankton aggregations were present over much of the survey region. Fish and zooplankton could be identified by their respective scattering characteristics with fish schools scattering more strongly at 38 kHz, and zooplankton scattering more at 200 kHz. Fish schools were typically located in dense aggregations very near (within 10 m) of the sea floor or in less dense aggregations in the middle of the water column (Fig. 13a). Zooplankton aggregations were found in the bottom half of the water column (during daytime hours), typically in a thick layer between 40 and 100 m depth (Fig. 13b). There was spatial variability in the thickness and intensity of the zooplankton aggregations. Zooplankton aggregations were observed migrating upward vertically at dusk.

Prey Sampling

Prey sampling trawls were conducted to compliment the prey mapping. Net tows and the CATS tag videos revealed zooplankton were primarily euphausiids (krill), although some amphipods were also caught. Net catch samples were photographed for identification and measurement post-cruise (Fig. 14). Fish species present were noted from records provided by fisherman in the area and included rockfish, cero, and other bottom-associated fish. Krill and other zooplankton samples are being analyzed (Chiang) to determine levels of nitrogen and carbon stable isotopes, mercury and organic pollutants.

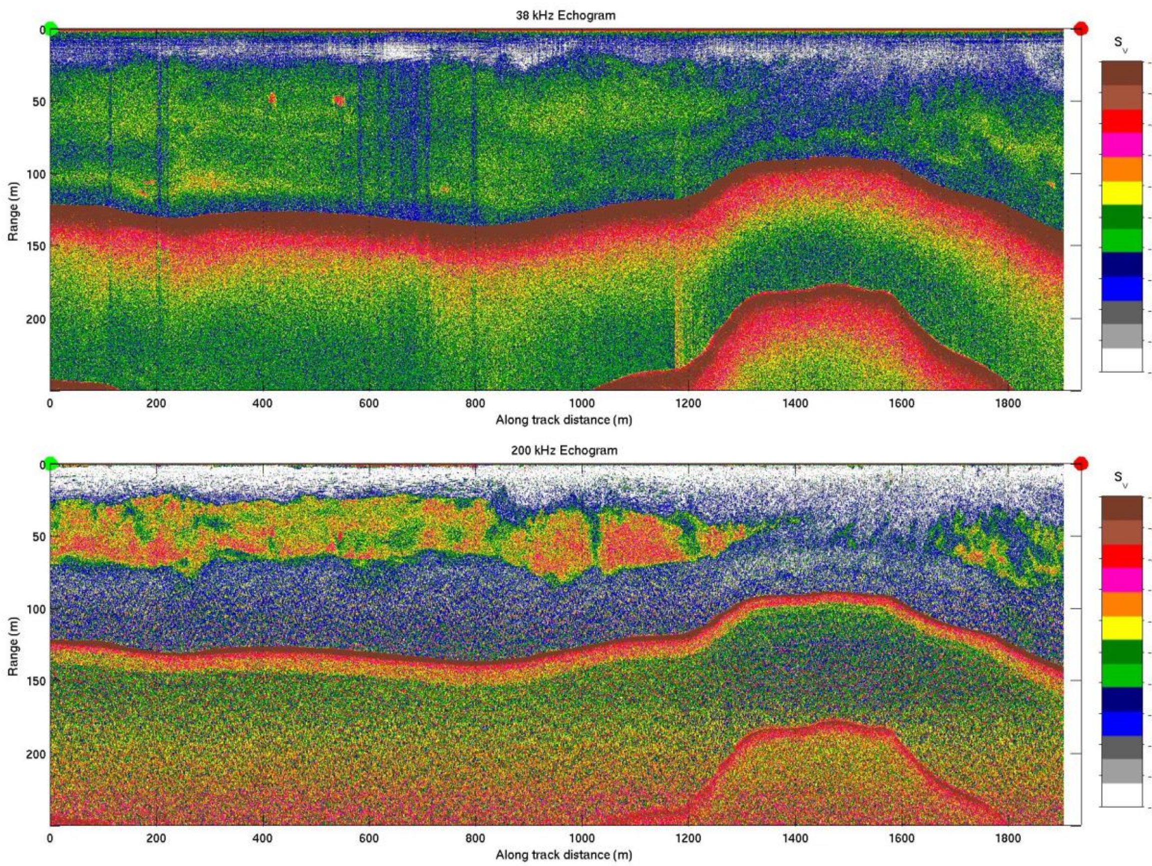

Figure 13. Echograms showing backscatter at 38 (top) and 200 (bottom) kHz. The x and y axes are distance and depth respectively. White and blue colors represent less backscatter with yellows and red colors representing stronger scattering. Krill aggregations are clearly seen in the 200 kHz echogram (bottom) as the large yellow and red patches between 25 and 75 m depth. Fish aggregations can be seen in the 38 kHz echogram (but not the 200 kHz echogram) as a thin layer at a depth of ~100 m. The dark red/brown line between 100 and 150 m is the seafloor. The two bright red spots in the 38 kHz echogram (at a depth of 50 m and between 400 and 600 m distance) are possibly foraging blue whales.

Figure 14. Euphausiids (krill) caught in net tows collected on 26 February 2016. These appear to be the predominant prey for foraging blue whales in the region.

By combining the tag data with the prey mapping, it is possible to examine how the whale's movements underwater are affected by the distribution of their prey. An example of this is can be observed when the dive profile of the tagged whale is overlaid on the acoustic echogram (Fig. 15). While these two data sets are not co-located (i.e. the echosounder and whale were not at the exact same location), the data show that the whale's dive depth and dive patterns change as the prey distribution changes (moves shallower) as the prey migrate towards the surface in the evening.

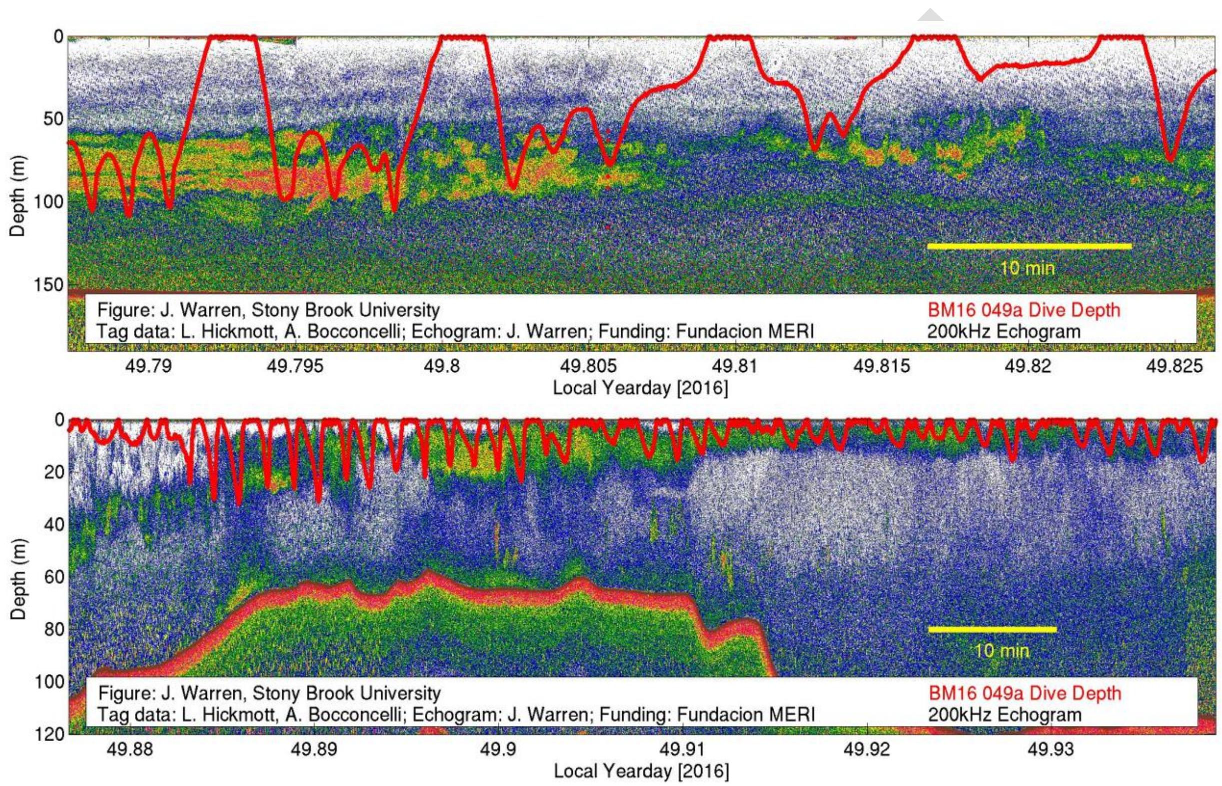

Figure 15. 200 kHz echograms show the distribution of krill with the dive depth of whale BM16_049a (tagged on 18 Feb 2016) overlaid. Whale dive patterns and maximum depth varied as the krill migrated shallower at dusk.

CATS Tag

During the cruise four CATS tags were deployed on three different blue whales (Table 6). Akin to DTAG data, these data are complex and require specialist analysis. Paolo Segre is leading this analysis. Preliminary analysis of video data revealed euphausiid krill prey and the whalesucker (*Remora australis*) (Fig. 16).

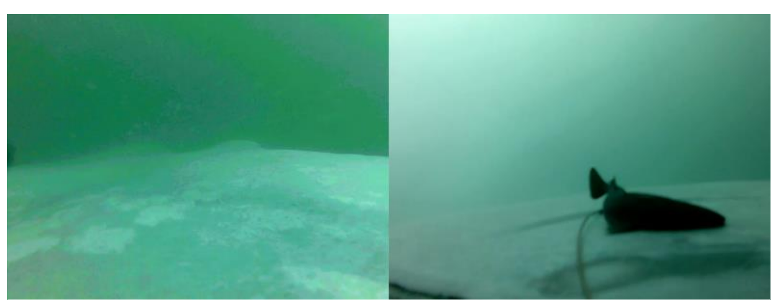

Figure 16. Front (left) and back (right) images from a CATS tag deployment, with a whalesucker in view.

Date	Animal ID	Age Class	Deployment ID	Deployment Time (local)	Deployment Location
22-Feb-2016	Bm045	Adult	froback_12_2_23	11:53	-42.85215 -72.8705
24-Feb-2016	Bm050	Adult	froback_8_2_25	10:55	-42.62291 -72.90034
28-Feb-2016	Bm060	Adult	froback_12_2_28	16:43	-43.02324 -72.91603
29-Feb-2016	Bm060	Adult	froback_8_2_29	10:54	-43.08707 -72.97556

Table 6. Summary information for the four CATS tag deployments.

Impact and Future Work

As in previous years the cruise was a success, with all objectives being achieved. The collaborations with Joseph Warren and Paolo Segre have resulted in new, previously unknown aspects of foraging and prey availability in the GoC. Since the 2015 cruise, one peer reviewed paper has been published on photogrammetry of GoC blue whales, DTAG data has been presented at international conferences, including the 'Fourth International Conference on the Effects of Noise on Aquatic Life' held in Ireland, and Saddler et al. have submitted a DTAG acoustics paper for peer review. The collaborative group of international scientists conducting this study of blue whales in the GoC continue to analyse the collected data and champion the conservation of blue whales and the wider GoC ecosystem. This is being undertaken by presenting their research at conferences, universities and in meetings with conservation managers and stakeholders in Chile.

Future efforts aim to include further prey mapping and detailed investigation of the risk of ship strikes to this population. The preliminary evidence collected here, indicates that migration of prey to the sea surface at night, may greatly increase the likelihood of ship strikes on blue whales in the GoC during the hours of darkness, as whales remain near the surface to feed. Planned research efforts during 2017 will look to address this question specifically.

Acknowledgments

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Appendix I

Photo-identification images of the 70 blue whales photo-identified between 2014 and 2016.

 Chile14_Bm001 (Left Dorsal)	 Chile14_Bm001 (Right Dorsal)
 Chile14_Bm002 (Left Dorsal)	 Chile14_Bm002 (Right Dorsal)
 Chile15_Bm002 (Left Dorsal)	 Chile15_Bm002 (Right Dorsal)
 Chile14_Bm003 (Left Dorsal)	 Chile14_Bm003 (Right Dorsal)
 Chile15_Bm003 (Left Dorsal)	 Chile15_Bm003 (Right Dorsal)
 Chile14_Bm004 (Left Dorsal)	 Chile14_Bm004 (Right Dorsal)


Chile14_Bm005 (Left Dorsal)


Chile14_Bm005 (Right Dorsal)


Chile16_Bm005 (Left Dorsal)


Chile16_Bm005 (Right Dorsal)


Chile15_Bm006 (Left Dorsal)


Chile15_Bm006 (Right Dorsal)


Chile15_Bm007 (Right Dorsal)


Chile15_Bm008 (Left Dorsal)


Chile15_Bm008 (Right Dorsal)


Chile15_Bm009 (Left Dorsal)


Chile15_Bm009 (Right Dorsal)


Chile15_Bm010 (Left Dorsal)


Chile15_Bm010 (Right Dorsal)


Chile16_Bm010 (Right Dorsal)


Chile15_Bm011 (Left Dorsal)


Chile15_Bm011 (Right Dorsal)


Chile15_Bm012 (Left Dorsal)


Chile15_Bm012 (Right Dorsal)


Chile15_Bm013 (Left Dorsal)


Chile15_Bm013 (Right Dorsal)


Chile15_Bm014 (Left Dorsal)


Chile15_Bm014 (Right Dorsal)

	
Chile15_Bm015 (Left Dorsal)	Chile15_Bm015 (Right Dorsal)
	
Chile15_Bm016 (Left Dorsal)	Chile15_Bm016 (Right Dorsal)
	
Chile15_Bm017 (Left Dorsal)	Chile15_Bm017 (Right Dorsal)
	
Chile15_Bm018 (Left Dorsal)	Chile15_Bm018 (Right Dorsal)
	
Chile15_Bm019 (Left Dorsal)	Chile15_Bm0019 (Right Dorsal)
	
Chile16_Bm019 (Left Dorsal)	Chile16_Bm0019 (Right Dorsal)

 Chile15_Bm020 (Left Dorsal)	 Chile15_Bm020 (Right Dorsal)
 Chile15_Bm021 (Left Dorsal)	 Chile15_Bm021 (Right Dorsal)
 Chile15_Bm022 (Left Dorsal)	 Chile15_Bm022 (Right Dorsal)
 Chile15_Bm023 (Left Dorsal)	 Chile15_Bm023 (Right Dorsal)
 Chile15_Bm024 (Left Dorsal)	 Chile15_Bm024 (Right Dorsal)
 Chile15_Bm025 (Left Thorax)	 Chile15_Bm025 (Right Thorax)


Chile15_Bm026 (Left Dorsal)


Chile15_Bm026 (Right Dorsal)


Chile16_Bm026 (Left Dorsal)


Chile16_Bm026 (Right Dorsal)


Chile15_Bm027 (Left Dorsal)


Chile15_Bm028 (Left Dorsal)


Chile15_Bm028 (Right Dorsal)


Chile15_Bm029 (Left Dorsal)


Chile15_Bm029 (Right Dorsal)


Chile16_Bm029 (Left Dorsal)


Chile16_Bm029 (Right Dorsal)

<table>
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Chile15_Bm030 (Right Dorsal)</td></tr>
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Assigned new number during 2016 analysis.</td></tr>
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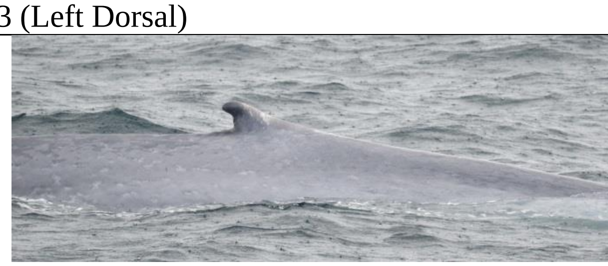
Chile16_Bm034 (Left Dorsal)</td><td>
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Chile16_Bm036 (Right Dorsal)

Chile16_Bm037 (Left Dorsal)

Chile16_Bm038 (Left Dorsal)

Chile16_Bm039 (Left Dorsal)

Chile16_Bm039 (Right Dorsal)

Chile16_Bm040 (Left Dorsal)

 Chile16_Bm041 (Left Dorsal)	 Chile16_Bm041 (Right Dorsal)
 Chile16_Bm042 (Left Dorsal)	 Chile16_Bm042 (Right Dorsal)
 Chile16_Bm043 (Left Dorsal)	
 Chile16_Bm044 (Right Dorsal)	
 Chile16_Bm045 (Left Dorsal)	 Chile16_Bm045 (Right Dorsal)
 Chile16_Bm046 (Left Dorsal)	 Chile16_Bm046 (Right Dorsal)


Chile16_Bm047 (Left Dorsal)


Chile16_Bm048 (Left Dorsal)


Chile16_Bm048 (Right Dorsal)


Chile16_Bm049 (Left Dorsal)


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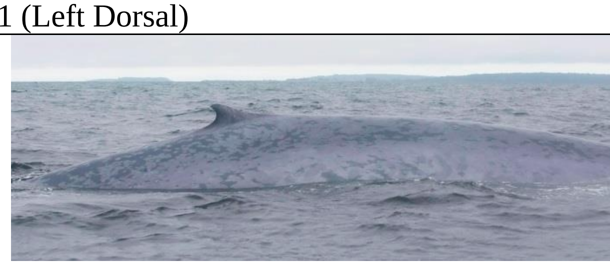
Chile16_Bm051 (Left Dorsal)


Chile16_Bm052 (Left Dorsal)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Chile16_Bm053 (Left Dorsal)


Chile16_Bm053 (Right Dorsal)


Chile16_Bm054 (Left Dorsal)


Chile16_Bm054 (Right Dorsal)


Chile16_Bm055 (Left Dorsal)


Chile16_Bm055 (Right Dorsal)


Chile16_Bm057 (Right Dorsal)


Chile16_Bm058 (Left Dorsal)


Chile16_Bm058 (Right Dorsal)


Chile16_Bm059 (Left Dorsal)


Chile16_Bm059 (Right Dorsal)


Chile16_Bm060 (Left Dorsal)


Chile16_Bm060 (Right Dorsal)


Chile16_Bm061 (Left Dorsal)


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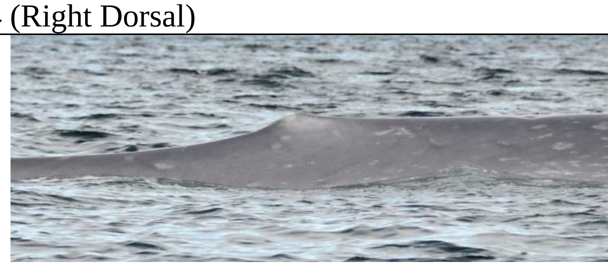
Chile16_Bm064 (Right Dorsal)


Chile16_Bm065 (Left Dorsal)


Chile16_Bm065 (Right Dorsal)


Chile16_Bm066 (Left Dorsal)


Chile16_Bm067 (Right Dorsal)


Chile16_Bm068 (Right Dorsal)


Chile16_Bm069 (Left Dorsal)


Chile16_Bm069 (Right Dorsal)


Chile16_Bm070 (Left Dorsal)